The effect of air velocity on moisture buffering

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Abstract. Hygoscopic finishing materials improve the indoor hygrothermal comfort and air quality, as they reduce the extremes of variation in relative humidity. This property, known as moisture buffering, is related to the capacity of hygroscopic materials to adsorb and desorb moisture from the air. Air velocity plays an important role on the sorption performances of materials: increasing the air speed leads to increased moisture buffering capacity. In order to obtain comparable results, several moisture buffering protocols require the air speed to be constant and around 0.1 m/s during tests. However, those tests are usually performed in climatic chambers, where air speed cannot be controlled and the flow may not be homogenous. The aim of this study is to demonstrate, that positioning test specimens in different locations within the same chamber gives different moisture buffering value results, due to the non-homogenous air speed distribution. For this reason, air velocity has been monitored, measuring the differential pressure and air speed in different locations in a climatic chamber. Moisture buffering tests have been performed in six locations of the chamber and a correlation between the two analyses has been evaluated. The significance of this paper is to understand the relationship between air speed and moisture buffering performances, in order to determine an air velocity correction factor, which enables the moisture buffering value to be evaluated when existing protocols cannot be adhered.

1 Introduction

The indoor air quality in modern buildings has decreased, since building enclosures have been made more resistant to heat losses, due to their higher air tightness and heavy insulation [1]. As consequence of this approach, there is a higher concentration of pollutant and an unregulated humidity exchange between the indoor and outdoor, which has the potential to leads to a decrease of occupant's health and well-being. In particular, Relative Humidity (RH) may increases respiratory infection, and help the proliferation of viruses and bacteria, if there are too high or too low levels of humidity in the indoor [2]. According to [3], RH should be maintained between 40% and 60%, to reduce health risks and improve indoor thermal comfort.

To improve indoor air quality, Heating, Ventilation and Air Conditioning (HVAC) systems have been developed to guarantee optimal indoor humidity level [4]. Nevertheless, these devices demand a regular maintenance, a good understanding of their operation and performance, higher costs and in particular, higher energy consumption [1].

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In order to reduce HVAC use, research focused on the moisture buffering concept in the indoor environment [5]. Moisture buffering refers to the ability of hygroscopic materials to moderate indoor humidity fluctuations, by adsorbing and desorbing water vapour from the room air. The application of materials, like clay and gypsum, on indoor surfaces reduces the extreme highs and lows of RH in the buildings, improving indoor hygrothermal comfort and health.

To measure the moisture buffering properties of surface materials, three protocols were introduced (NORDTEST [5], ISO 24353 [6], JIS A 1470-1 [7]). These tests are based on the step-response method, which consists of monitoring the mass change of a test specimen, when RH cyclically changes from high to low levels.

Protocols requires the air speed to be constant, as it influences the dynamic water adsorption property. Consequently, the NORDTEST protocol prescribes the air speed on the specimen's surface to be around 0.1 m/s during tests, which should equate to a surface film resistance of $5.0\times10^7 m^2$ s Pa/kg. The ISO 24353 recommends 13.3 m^2 h Pa/μg, which after conversion corresponds to $4.8\text{x}10^{13}$ m^2 s Pa/kg, while the JIS A 1470 proposes a value between 2.4 and 9.4 m^2 s Pa/kg. The Japanese standard and the NORDTEST presented similar values. However, the value introduced in the ISO shows a 10^6 higher values from the value proposed by the other two standards, which leads to different moisture buffering performances between the three protocols [8].

Moreover, it is not always possible to control the air velocity during testing, as tests are performed in climatic chambers, which may not allow the manual control of the air speed, or tests are performed in jars or boxes, where it is not easy to assure a constant air flow. For this reason, it is necessary to better understand the correlation between air velocity and moisture buffering.

This paper analyses the effect of air speed on the moisture buffering performance of clay plaster. NORDTEST protocol was followed and the clay sample was moved in 6 different locations within the same climatic chamber. This study aims to demonstrate the air speed, coming out from the inlet fan is higher than 0.1 m/s and the air distribution is not uniform across the chamber, leading to different air velocity and consequently, to different moisture buffering results. The significance of this research is to show the sensitivity of moisture buffering to small air speed variation, and to introduce the idea of a velocity correction factor, to adjust results obtained with different air speeds.

2 Materials and Method

2.1 Materials

Undercoat clay plaster, composed of natural clay and sand, was used, as it has good moisture buffing property [8]. The air dry clay plaster was mixed with 20% mass of water by mechanical mixing in the laboratory, according to the workability of the plaster. Specimen was cast in 150x150x20 mm moulds made with phenolic-faced plywood, and stored for 28 days in an environmental chamber at 20°C and 60% RH. The dry density is 1258 kg/m^3. A single specimen was repeatedly used for this study, to eliminate variability due to material properties and composition.

2.2 Method

2.2.1 Air Velocity Measurement

The air speed was measured in the climatic chamber (ACS DY110) with an air velocity transducer (TSI 8455) with ±2% accuracy. The climatic chamber has an accuracy of ±2% for

RH and ±0.2°C for the temperature. The climatic chamber was kept at constant temperature and RH (23°C and 50%). The air speed was measured in 27 different spots (at three different heights and 9 location in the horizontal plane), as represented by the dots in Fig. 1. The sensor was kept horizontal and with the probe facing the back of the chamber, as the main air flow is directed towards the inlet and outlet fans, placed on the back side. Records were taken every minute for 15 minutes, which is the time for the air speed to stabilise. The data logger PicoTech TC-08 recorded the data in volts, which were then converted in m/s though the formula provided by the anemometer producer [9].

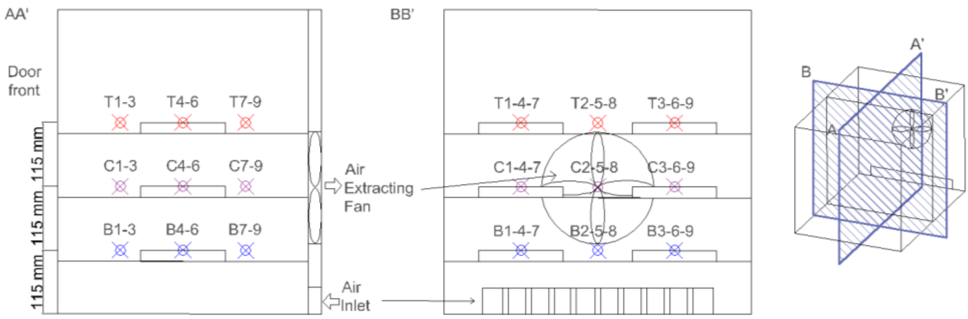

Fig. 1 Schematization of the climatic chamber and the distribution of recorded spots for the anemometer (dots) and for the sample (green hatch)

2.2.2 Moisture Buffering Measurement

The sample was placed on a mass balance inside the climatic chamber preconditioned for 24h at 54% RH and 23°C, until the mass varied by less than 5%. The mass of the specimen was measured every minute. Temperature and RH in the climatic chamber were monitored with humidity and temperature sensors. The scales were placed at a measured height, in order to have the surface of sample at the same high of the air speed spots. The moisture buffering method used was the NORDTEST protocol [5]. The specimen was exposed to 6 moisture buffering cycles. Each cycle consisted of 8 hours of high humidity (75%) and 16 hours of low humidity (33%). The last three cycles were analysed, as the samples reaches its balance with the environment after the third cycle. The moisture buffering test was performed in 6 locations around the climatic chamber, in order to evaluate the effect of air distribution variation within the same chamber. Middle tests were performed once, as in previous testing it was assured the repeatability of the moisture buffering test in the same climatic chamber, with same sample and test condition (coefficient of less than variation 1%). In future these tests will be repeated. The top and bottom tests were repeated twice, to evaluate the accuracy of the results. Fig. 1 shows the 6 locations of the specimen. The Moisture Buffering Value (MBV) is expressed in g/(m^2%RH).

3 Results

Table 1 shows the average of the 27 air velocity measurements. Each spot presents different air speed, which demonstrates the air flow inside the climatic chamber is not constant. The results do not show a strong pattern, which makes difficult to find noticeable differences between levels and location. The only clear trend is observable in the central level, where the air velocity is lower, compared to the other two levels. The results presented are from a single experiment of 27 records using a directional, general purpose, air velocity probe. A further investigation is proposed using an omni-directional probe to limit the influence of any directional sensitivity in the positioning of the sensor within the climate chamber.

Table 1 Average air speed values (m/s) for each spot

Spot number	Bottom	Centre	Top
1	0.62	0.13	0.44
2	0.54	0.13	0.36
3	0.61	0.16	0.26
4	0.20	0.29	0.28
5	0.34	0.20	0.17
6	0.25	0.21	0.94
7	0.18	0.35	0.71
8	0.21	0.19	0.38
9	0.25	0.31	1.11

Fig. 2 presents the adsorption and desorption curve of the fourth test cycle. Adsorption is higher, when the sample is placed on the left side of the climatic chamber and on the top shelf (67 g/m^2 peak to peak), and it is lower, when it is on the centre shelf on the right (52 g/m^2). The overall trend indicates that the top and bottom shelf have always higher moisture buffering performance, probably because of the higher air velocity and more irregular air movement. The left side shows always higher sorption values, which corresponds on an increase of a minimum 7% more sorption capacity on the centre shelf, until a maximum of 12% on the top shelf. The centre shelf presents the most similar results between the left and the right test and the lowest moisture buffering sorption curve.

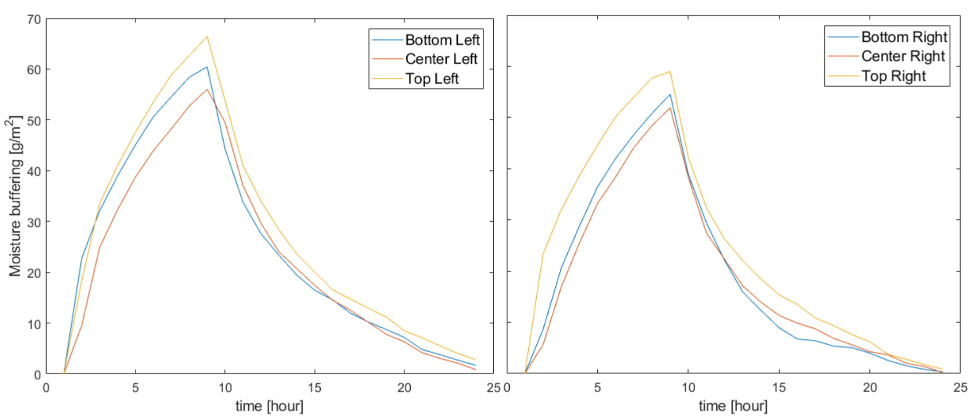

Fig. 2 Clay performances when sample is placed on the left and right side of the climatic chamber

A statistical analysis was performed on these data, in order to evaluate the variability of the test (when the specimen was tested in identical positions), and to show the differences presented in Fig. 2 are significant. The two tailed t-test analysis highlighted that repeating the test twice, the bottom and top right tests show no significant difference between the results ($p>0.05$), while testing in the top left shows results in statistically different MBV values ($p=0.02$), as shown in Table 2. In this case, it is necessary to repeat the test. Comparing the results between each location, there is a statistically significant difference between each shelf, while the differences do not appear to be so clear when comparing left to right side curves.

Table 2 Comparison of the MBV (g/(m^2%RH)) of the last three cycles

Cycle	Top Right		Top Left		Bottom Right		Bottom Left	
	1	2	1	2	1	2	1	2
4th	1.68	1.63	1.85	1.68	1.47	1.61	1.68	1.68
5th	1.72	1.62	1.79	1.59	1.60	1.57	1.72	1.59
6th	1.86	1.65	1.81	1.64	1.28	1.56	1.86	1.64

4 Analysis and Discussion

The moisture buffering results are compared with the air speed in Table 3. The final air speed is calculated measuring the average air speed of spot 1, 4 and 7 for the left side and 3, 6, 9 for the right side, as those spots cover the area, where the sample is placed.

Table 3 Moisture buffering values in the 6 locations

Sample Location	MBV (g/m^2%RH)	Average Air Speed (m/s)
Bottom Right	1.52	0.43
Bottom Left	1.76	0.34
Middle Right	1.49	0.23
Middle Left	1.67	0.26
Top Right	1.76	0.77
Top Left	1.82	0.48

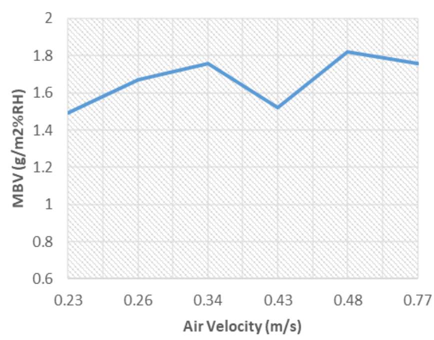

Fig. 3 Correlation between moisture buffering values and air velocities

Results in Table 3 showed different MBV values depending on the location of the sample. The central shelf, which has lower air speed, presents lower MBVs, while the top shelf presents the highest values. Looking at the correlation between air speed and MBV (Fig. 3), a direct dependency between air velocity and moisture buffering performance were noticed.

The MBV increases, when the air speed increases, as exception for the bottom right value. It not possible to make final conclusion on this data, as it is still necessary to repeat moisture buffering tests, to be sure of the repeatability of the MBV. It is also necessary to use an omnidirectional anemometer, as it is possible that the sensors currently used for this study were not placed correctly on its location, leading to a wrong reading of the air velocity. That would explain the drop in MBV in Fig. 3.

The effect of such small air velocities on MBV does not leads to important changes in the MBV classification for the clay material used for this study. However, effect on MBV can be bigger in other materials, and it demonstrated the strong effect of air movement on the dynamic sorption. Consequently, it is worth it to further analyse and develop this topic, by improving the test and by using different materials.

5 Conclusion

This study focused on analysis of the dependency of the sorption capacity of finishing materials to the air velocity, to better understand their moisture buffing properties. In particular, the aim was to observe how clay plaster's moisture buffering performance varies, by simply moving the sample around the climatic chamber, around where different air velocities were previously recorded with an omnidirectional anemometer.

The air velocity transducer measured higher air velocities on the top and bottom of the climatic chamber, but the results do not show a noticeable pattern between the spots. Measurements needs to be repeated with an omnidirectional sensor, capable to measure secondary air flows.

Clay was tested, by applying the NORDTEST and moving the samples in 6 locations in the climatic chamber. Results showed different MBV values depending on the location of the sample, which is consequent to the different air velocities measured. It seems there is a correlation between air speed and moisture buffering: MBV increases, when the air speed increases. However, more analysis is necessary to confirm the trend.

In this paper, it was demonstrated how sorption properties are sensitive to small air speed variation, highlighting the importance of having full control of air movement during testing. As it is not always possible to control the air velocity, this study highlights the necessity to further analysis on this field, to facilitate laboratories, which do not have the equipment to perform a moisture buffering test in a homogenous and regulated environment. The understanding of the correlation might be useful to improve moisture buffering testing and to make results between different laboratories repeatable and comparable, by introducing an air speed conversion factor, which standardise the MBV, independently on the air velocity the test is performed.

A better understanding of the moisture buffering influencing factor may help to understand the impact of finishing materials in buildings in order to increase the use of hygroscopic material to improve indoor air quality and to help reducing the use of energy consuming conditioning systems.

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